Lexical Transfer based on Bi-Lingual Signs
- Towards Interaction during Transfer -

Jun-ichi Tsujii, Kimikazu Fujita

Centre for Computational Linguistics
Department of Language and Linguistics
UMIST, P.O.Box 88, Manchester M60 1QD, United Kingdom
tsujii@ccl.umist.uk.ac

1. Introduction

"Lexical Transfer" has always been one of the main sources of troubles in MT.

The research in transfer based MT systems has focussed on discovering an appropriate level of linguistic descriptions for translation, at which we can specify "translation relations" (or transfer rules) in a simple manner. In the extreme, the Eurotra project have introduced the principle of "Simple Transfer" which means that most parts of descriptions of SL objects, especially their geometrical structures, should be preserved in TL during the transfer except for their lexical items. However, structural mismatches between two languages are frequently caused by lexical differences so that the effort of minimizing structural changes with "lexical transfer" untouched seems to have encountered serious difficulties.

Besides structural changes caused by lexical transfer, selecting equivalent target words for source lexical items has been one of the hardest problems in MT. A single source lexical item should be translated into different target expressions (words or phrases), depending on linguistic or extra-linguistic contexts in which it actually appears. Determining appropriate target equivalents for source words is one of the typical processes which require "inferences" based on "extra-linguistic" knowledge and/or information conveyed by other parts of texts.

Because individual languages have their own ways of structuring the worlds by their words and the process of lexicalization in language is more or less arbitrary, we can hardly expect to have general theories of lexical correspondences across languages. We have to accumulate idiosyncratic "knowledge" about individual lexical correspondences as bi-lingual knowledge. The bi-lingual knowledge used in the transfer phase of actual MT systems mostly consists of such idiosyncratic lexical correspondences.

What sorts of information are necessary to select appropriate target equivalents and what structural changes are caused by "lexical transfer" are highly dependent on language pairs and individual words. What we need is to prepare a framework in which such bi-lingual knowledge about idiosyncratic "lexical correspondences" can be described in natural manners.

Our approach in this paper follows the general trend in CL which emphasizes the role of lexicon in linguistic theories, and in particular, it shares the idea with [Whitelock, 1988] which proposed to specify most of bi-lingual correspondences in lexicon.

Unlike former approaches, however, we explicitly introduce bi-lingual signs (eg. "signs" defined by words - mono-lingual signs - of two languages), and lexical descriptions which play the central role in the transfer are given to these signs. Bi-lingual signs in our framework not only link the local linguistic structures of two languages where the corresponding two mono-lingual signs appear, but also, by behaving as a logical predicate, they connect linguistic-based processings in MT with inference processes. We also show that complicated structural changes which are often required in translation of remote language pairs like English and Japanese can be captured as special types of logical inferences.

The framework has the following advantages over conventional methods.

(I)Reversibility of Bi-lingual Dictionaries
(II)Natural Interfaces between Knowledge-based
(Inference) Processings with MT
(III)Easiness of Paraphrasing using Different Words

We are now being engaged in developing an MT system for mono-lingual users, the users who don't have enough knowledge about the target language. In such an environment, it is crucial for the system to pose appropriate questions to users in order to disambiguate ambiguities. In particular, to formulate appropriate questions for resolving ambiguities during the transfer phase is important and much more difficult, if we compared them with ambiguities in the analysis phase. We have to formulate questions which make differences in readings explicit, the differences which mono-lingual speakers of the source language usually do not recognize. The advantage (III) of our framework will play an important role in this question formation process.

2. Bi-lingual Signs as Logical Predicates

In a naive formal semantics (FS in short), the meaning of a word, say "to run", is expressed by a predicate (say, RUN) which corresponds straightforwardly to the surface word. In short, based on this correspondence of basic units in the two domains, i.e. words in the linguistic domain and predicates in the domain of logic, FS has developed theories of relating complex expressions of the two domains which consist of more than one basic units.

The (truth-conditional) meaning of a sentence

(1) The teacher runs the program

may be expressed, for example, as

(2)(exist e)(exist x)(exist y)
{RUN(e)&ARG1(e,x)&ARG2(e,y)
TEACHER(x)&PROGRAM(y)}

We need more sophisticated notations for expressing the meanings of articles, quantifiers etc., and also in MT, we have to preserve other kinds of information which are conveyed by linguistic forms but can hardly be expressed in logical formulae (topic, focus, etc). Actually, we think of QLF - quasi-logical form - type of descriptions [Hyan - 1990] in which such information relevant to MT is encoded and annotated in logical formulae. However, for the sake of simplicity, we will ignore these required sophistications and use throughout this paper much simplified notations such as (2). We will also omit quantifiers in the following which are irrelevant to the current discussion. But even in more sophisticated representations such as QLF, the fact that the meanings of "*teacher*", "*to run*" and "*program*" are expressed straightforwardly by the predicates like TEACHER, RUN, and PROGRAM is untouched.

The meaning representation as such is purely mono-lingual. The truth condition of being "*teacher*" is assumed to be expressed by the predicate TEACHER.

The framework which we need for translation is essentially similar to the ones in FS, i.e. a framework of systematically relating complex expressions of two infinite domains, the domains of expressions of source and target languages. However, as we said, the naive assumption in FS of straightforward correspondences of basic units does not hold in our domains.

"*To run*", for example, have to be translated into several different Japanese verbs. While "*to run*" in the example (1) is translated to "*jikkousuru*" in Japanese, "*to run*" in "*the teacher runs the big*

company" should be translated differently (in this case, "*un'eisuru*").

One can claim that "*to run*" is mono-lingually ambiguous and that the above two senses should be distinguished by using different predicates, namely RUN1 and RUN2. This approach leads us to the well-known difficulty that the distinction of senses of single lexical items is, except for obvious cases, notoriously subjective and subjective judgements given by lexicographers have caused serious troubles in actual MT systems such as difficulties in maintaining consistency between mono-lingual and bi-lingual dictionaries, etc. Furthermore, required fineness of distinction of word senses highly depends on the target language (source words are translationary ambiguous : [Tsujii, 1986]).

The basic idea of bi-lingual signs is very simple. Instead of using predicates corresponding directly to surface words like RUN or predicates corresponding to intuitively distinguished senses like RUN1 and RUN2, we use pairs of lexical items of two languages as predicates. That is, we use [RUN:JIKKOUSURU], [RUN:UN'EISURU] etc. as basic predicates to express meanings of sentences.

The bi-lingual sign [RUN:JIKKOUSURU] is a predicate which expresses the truth condition an event "e" should satisfy in order to be described by "*to run*" in English and "*jikkousuru*" in Japanese. Note that [RUN:JIKKOUSURU] expresses not only one disambiguated sense of "*to run*" but also one disambiguated sense of the Japanese verb "*jikkousuru*" ("*jikkousuru*" should be translated into several English verbs including "*to run*", "*to carry out*", "*to execute*", "*to implement*", "*to practice*", etc., depending on contexts). [RUN:JIKKOUSURU] expresses the conjunction of truth conditions of "*to run*" and "*jikkousuru*".

Though each bi-lingual sign basically corresponds to a lexical transfer rule (of the most simple sorts like "*to run*" $\longleftrightarrow$ "*un'eisuru*", "*to run*" $\longleftrightarrow$ "*jikkousuru*", etc.: we will extend the bi-lingual signs to treat more complex lexical transfer in section 4), we give them independent status as predicates. We can use them to express truth conditional meanings of source and target linguistic forms and also to represent extra-linguistic knowledge about the world (domain knowledge).

As [Sadler 1990] pointed out, compared with the methods using arbitrary predicates (or units of frames, if you like), this method is well-motivated in selecting basic predicates (or frames). We can expect the set of bi-lingually defined predicates to have appropriate granularity for representing knowledge for translation, at least a necessary, if not sufficient, level of granularity for translation of given two languages.

Furthermore, we can use logical formulae to specify mutual relationships among bi-lingual signs, which means that we can specify explicitly "logical" relationships among lexical transfer rules. As we discuss later, this explicitness of relationships among "lexical transfer rules" enhances the reversibility of rules and also provides the system with the capability of paraphrasing, which is crucial for disambiguation in the transfer phase by dialogue.

3. Definition of Bi-lingual Signs

We assume here a conventional transfer based MT system where the mono-lingual analysis and transfer phases are executed separately by using separate mono-lingual and bi-lingual dictionaries (More detailed discussion on the interface of these two stages - see Section 7). The analysis phase of English produces the following schema of logical formula (3) as the description of (1), instead of the logical formula (2).

(3) {[RUN: 1?](e)&ARG1(e,x)&ARG2(e,y)
&[TEACHER: 2?](x)&[PROGRAM: 3?](y)}

(3) is not a logical formula but a schema which represents set of possible formulae. [RUN: 1?] is a predicate schema, and by binding the variable 1? to a specific Japanese verb, we get a specific predicate such as [RUN:JIKKOUSURU], [RUN:UN'EISURU], etc. The transfer phase is taken to be a phase which identifies appropriate predicates in a schema of logical formulae produced by the analysis phase.

As in conventional transfer based MT systems, we use sortal restrictions on arguments for disambiguation, e.g. for identification of appropriate (bi-lingual) predicates. That is, predicates have their

own arities and their sortal restrictions on the arguments.

[RUN:UN'EISURU], for example, requires the argument-1 to be a human or an organization and the argument-2 to be an organization. These restrictions can be expressed simply by logical implications such as

(4) (→ [RUN:UN'EISURU](e)&ARG1(e,x)
[ORGANIZAION:SOSHIKI](x)v[HUMAN:NINGEN](x))

and

(5)(→ [RUN:UN'EISURU](e)&ARG2(e,x)
[ORGANIZAION:SOSHIKI](x)).

These formulae mean that if the event "e" satisfies the predicate [RUN:UN'EISURU], then the object related with the event by ARG2 (we call this object as the argument-2 of the event) should satisfy the predicate [ORGANIZATION:SOSHIKI], etc.

Because the event "e" is described in English by using "*to run*", it should satisfy one of the predicates of the predicate schema [RUN: ?1]. Assume that it satisfies [RUN:UN'EISURU], then the argument-2 of the event should satisfy [ORGANIZATION:SOSHIKI]. If the sort of the actual argument contradicts this constraint, then the event doesn't belong to the sort [RUN:UN'EISURU] and it cannot be described by the Japanese verb "*un'eisuru*". The lexical transfer "*to run*" to "UN'EISURU" is judged not appropriate in this case.

Logical implications are used to express various, ontologically different relationships between two formulae, which should be treated differently in MT. The consequence parts of the implications in the above examples express constraints which an event "e" and the participants of the event (arguments) should satisfy to be describable by both "*to run*" and "*un'eisuru*", eg. the constraints an event belonging to the sort [RUN:UN'EISURU] should satisfy.

The other type of relations expressed by logical implications is a hierarchical relationship among sorts such "[TEACHER:SENSEI] is a [HUMAN:NINGEN]", etc.

These two types of implications are distinguished by the first argument of → as follows, because they are used differently in translation (more detailed notation, see Section 5).

(5') (→ C [RUN:UN'EISURU](e)&ARG2(e,x)
[ORGANIZAION:SOSHIKI](x))

(6) (→ S [TEACHER:SENSEI](x)
[HUMAN:NINGEN](x)).

The consequent parts of C-type implications like (5') can be arbitrary complex. However, because it has been already known [Tsujii, 1986] [Hiyan, 1990] that simple sortal restrictions on arguments are often useful for disambiguating transfer ambiguities and also that the checking of sortal consistency based on sort-hierarchies defined by simple S-type implications like (6) can be implemented in a computationally efficient manner , we introduce notational conventions in the definition part of bi-lingual signs to express sortal restrictions on arguments.

(7)(Def-Pred
[RUN:UN'EISURU]
{arg1 := [HUMAN:NINGEN]v[ORGANIZATION:SOSHIKI],
arg2 := [ORGANIZATION:SOSHIKI]})

(8)(Def-Pred
[RUN:JIKKOUSURU]
{arg1 := [HUMAN:NINGEN],
arg2 := [PROGRAM:PUROGURAMU]})

The definition (7) shows that the predicate [RUN:UN'EISURU] has the arity two and the arguments have sortal restrictions expressed by (4) and (5) (or (5')). This definition is read also as a definition of an event sort [RUN:UN'EISURU]. Sorts of events are also organized into a hierarchy. We assume that objects/events are organized in separate hierarchies and that both hierarchies constitute lattices (we allow a sort to have multiple super-sorts).

From (3) (the schema of logical formulae for (1)), we know that argument-2 of the event "e" is filled by the variable "y" and that "y" satisfies some of the predicates in the predicate schema [PROGRAM: ?3] (i.e. "y" belongs to some sorts in the schema [PROGRAM: ?3]). If a sort-hierarchy shows that all the sorts in [PROGRAM: ?3] are inconsistent with [ORGANIZATION:SOSHIKI], then the attempt of describing the event "e" by "*un'eisuru*" in Japanese fails and the transfer ("*to run*" → "*un'eisuru*") is rejected. On the other hand, the variables x ("*teacher*") and y ("*program*") in the schema (3) may satisfy the sortal restrictions of [RUN:JIKKOUSURU] in (8) so that the transfer ("*to run*" → "*jikkousuru*") is taken as feasible.

As in LFG, we assume that semantic representations (logical forms) are related lexically with a certain level of descriptions of linguistic forms. Though LFG specifies the relations between functional structures and meaning representations (logical forms) in the mono-lingual lexicon of surface words, we specify them in bi-lingual lexicon, that is, in the "lexical" descriptions of bi-lingual signs (predicates).

The relation of grammatical functions and predicate arguments is specified in LFG by the following description.

run :
sub :=
obj :=
sem := [RUN <! sub> <! obj>]

In our framework, the specification of the relationships is done in the other way around. Note also that: because a bi-lingual sign (predicate) is defined by two languages (English and Japanese), the two relationships of (logical forms ⟷ English) and (logical forms ⟷ Japanese) are specified in the same place.

```
(9)(Def-Pred
   [RUN:UN'EISURU]
    {arg1 := [HUMAN:NINGEN]v[ORGANIZATION:SOSHIKI],
     arg2 := [ORGANIZATION:SOSHIKI],
     eng  := {head := {e-lex := run},
              agt  := <! arg1>,
              obj  := <! arg2>},
     jpn  := {head := {j-lex := un'eisuru},
              agt  := <! arg1>,
              obj  := <! arg2>}}  )
```

Here, in order to avoid further complications caused by changes of grammatical functions (passivization, etc.), we use thematic role representations as linguistic descriptions. In the above, <> shows a path description and ! in <> means the smallest description block (shown by {}) which contains the description block in which the ! appears.

4. Complex Structural Changes - Complex Bi-Lingual Signs

(9) in Section 3 shows a simple case of a lexical transfer where the lexical correspondence ("*to run*" $\longleftrightarrow$ "*un'eisuru*") doesn't interact with structures. The thematic role structures remain the same in the two languages. However, many cases have been observed where lexical transfers cause structural changes. It is also often the case that single words in English correspond to phrasal expressions in Japanese, and vice versa.

We may expect that classes of objects or events which can be expressed by single words in one language correspond to natural (not contingent) classes of objects/events, the classes whose truth conditions are naturally captured by single predicates in logical forms. Therefore, we prepare single bi-lingual signs for expressing their truth conditions if at least one of the languages has lexical items, even though the other language lacks corresponding words and use complex phrasal expressions to express the same classes of events/objects.

The followings show how our framework based on bi-lingual signs treat structural changes caused by lexical correspondences.

[A] Case Changes : English sentence "*I like him*" is usually translated into "*Il m'plait*" in French. Though one may think of (mono-lingual) levels of linguistic descriptions where this discrepancy of syntactic functions disappears, it seems more natural to take this discrepancy as bi-lingual phenomena, ie. the two languages have their own lexical items which capture the same states/events from their own view points.

In our framework, corresponding case elements in two languages are linked with each other through the same argument names of bi-lingual signs so that this sort of case changes can be treated in a simple way.

```
(Def-Pred
  [LIKE:PLAIRE]
   {arg1 := ,
    arg2 := ,
    eng  := {head := {e-lex := like},
             agt  := <! arg1>,
             obj  := <! arg2>},
    fre  := {head := {f-lex := plaire},
             agt  := <! arg2>,
             obj  := {! arg1>}})
```

[B] Lexical Inclusions of Arguments: A Japanese verb "*nuru*", for example, is translated into "*to paint*", "*to varnish*", "*to spread (bread with butter, dark wash around ..)*", "*to apply (paint)*" etc., depending on what is "*nuru*-ed". Some of the English verbs ("*to paint*", "*to varnish*", etc.) include the objects (in Japanese) in their meaning. For example,

(10a)	kabe-ni	penki-wo	nuru
	[n:wall	[n:paint	[v]
	-location]	-object]	
(10b)	(someone)	paints	the wall.
		[v]	[object]

This structural change is treated by the following definition of a bi-lingual sign [PAINT:PENKI-WO-NURU].

```
(11)
(Def-Pred
  [PAINT:PENKI-WO-NURU]
   {arg1 := ,
    arg2 := ,
    eng  := {head := {e-lex := paint-1}},
            agt  := <! arg1>,
            obj  := <! arg2>},
    jpn  := {head := {j-lex := nuru},
            agt  := <! arg1>,
            obj  := {head := {j-lex := penki}},
            loc  := <! arg2>}})
```

Note that Japanese verb "*nuru*" governs three dependents but one of them is in this definition filled in advance by a specific noun ("*penki*" - "*paint*" in English). The suffix -1 in paint-1 is for distinguishing the verb usage of "*paint*" from its noun usages.

[C] Lexical gaps: Quite a few number of English adjectives should be translated into clauses in Japanese, because Japanese simply lacks corresponding words. "*Efficient*" should be translated into a clause in Japanese as follows.

(12)	kouritsu	-ga	yoi
	[efficiency	[subject-marker	[good
	: n]	: pp]	: adj]

The phenomena is similar to the lexical inclusion except for the fact that this causes rather drastic changes in syntactic structures. In this paper, we assume that the descriptions on which transfer operations are performed are abstract enough so that the determination of syntactic categories etc. are carried out in the generation phase.

```
(Def-Pred
 [EFFICIENT:KOURITSU-GA-YOI]
 {arg1 := ,
  eng  := {head := {e-lex := efficient},
           obj  := <! arg1>},
  jpn  := {head := {j-lex := yoi},
           topic  := <! arg1>,
           obj  := {head := {j-lex := kouritsu}}
          }} )
```

[D] Category Changes : One of well-known examples of this is the correspondence between English verb "*to like*" and Dutch adverb "*graag*" (which roughly corresponds to the English adverb "*pleasantly*"). The mental state expressed by the verb "*to like*" is expressed not by a main verb but by an adverb in Dutch. This kind of phenomena has also been observed very frequently in translation between English and Japanese, ie. Verbs in English which take sentential complements (esp. infinitival clauses) are expressed specific adverbs modifying main clauses in Japanese which correspond to sentential complements in English.

The event expressed by the verb "*to manage*" (of the usage of "*to manage to do sth*") is captured by an adverb "*nantoka*" (somehow or other, with great efforts, etc) in Japanese. The adverb is used to modify the event expressed in English as an infinitive clause ("*to do sth*").

(13a)	watashi	-ga	nantoka	ronbun	-wo	shiage	-ta.
	[I:n]	[subject -marker	[somehow or other: adv]	[paper :n]	[object -marker]	[to complete : v]	[past]

(13b) I managed to complete {the/a} paper.

This correspondence is captured by the following definition.

```
(14)
(Def-Pred
 [MANAGE:NANTOKA]
 {arg1 := ,
  arg2 := [event:dekigoto],
  eng  := {head := {e-lex := manage},
           agt  := <! arg1>,
           evt  := <! arg2>},
  jpn  := { <! arg2>,
           agt  := <! ag1>,
           /adv := {head := {j-lex := nantoka}}}
  })
```

In this example, though the adverb "*nantoka*" is not the head (semantic governor) of the Japanese deep case description (jpn), it is converted into the predicate [MANAGE:NANTOKA] in the logical formula, and the rest of the jpn description into the arguments.

In order to treat this, we introduce new notations. {<! arg2>, /adv := {.1.}} means that the event/object described by this whole description block minus adv:={.1.} corresponds to the arg2 of the description block immediately above, and /adv:={..1..} is converted into a predicate at the logical level though it is not the head in Japanese description. By this notation, we can raise non-head elements in one language descriptions into predicates in logical formulae.

5. Definition of Sort Hierarchies

We distinguished in Section 3 two types of logical implications, S-type and C-type. We show that simple formulae of these two types are expressed in terms of sort hierarchies (S-type) and sortal restrictions on arguments (C-type), respectively. In this section, we introduce notations for more general forms of logical implications.

We will express simple S-type implications by the following notation.

(15)
(→ (S)
SUB:[TEACHER:SENSEI]
SUP:[HUMAN:NINGEN])

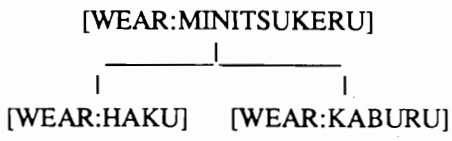
Because all sort-predicates are one-place predicates (ie. predicates with arity one), we don't indicate in this notation their argument explicitly by using variables.

Sort-subsort relationships can also be defined among event-sorts such as

(16)
(→ (S)
SUB:[WEAR:HAKU]
SUP:[WEAR:MI-NI-TSUKERU])
(17)
(→ (S)
SUB:[WEAR:KABURU]
SUP:[WEAR:MI-NI-TSUKERU]).

(16) and (17) defines the following sort hierarchy.

(18)



English verb "*to wear*" is a well-known example of translationary ambiguous words, i.e. when it is translated into Japanese, it should be translated into several different verbs including "*haku*"(to wear shoes), "*kaburu*"(to wear a hat), "*kakeru*"(to wear spectacles), "*kiru*"(to wear clothes), etc., depending on what is worn. However, we also have a complex expression "*minitsukeru*" in Japanese which preserves almost the same vagueness as "*to wear*" has.

Note that though "*minitsukeru*" is a complex expression which has the following construction, it is mapped into a single predicate because it corresponds to a single lexical item "*to wear*" in English.

(19)	sth-wo	mi-	ni	tsukeru.
	[obj]	[body :n]	[locative marker:pp]	[to put on: v]

The prediacte [WEAR:MI-NI-TSUKERU] can be defined in a way similar to [PAINT:PENKI-WO-NURU].

```
(20)
(Def-Pred
 [WEAR:MI-NI-TSUKERU]
  {arg1 := [NINGEN],
   arg2 := ,
   eng  := {head := {e-lex := wear},
            agt  := <! arg1>,
            obj  := <! arg2>},
   jpn  := {head := {j-lex := tsukeru},
            agt  := <! arg1>,
            obj  := <! arg2>,
            loc  := {head := {j-lex := mi}}}})
```

On the other hand, the definitions of [WEAR:HAKU] and [WEAR:KABURU] have more limited sortal restrictions on the argument-2 as follows.

```
(21)
(Def-Pred
 [WEAR:HAKU]
  {arg1 := [NINGEN],
   arg2 := [SHOES:KUTSU],
   eng  := {head := {e-lex := wear},
            agt  := <! arg1>,
            obj  := <! arg2>},
   jpn  := {head := {j-lex := haku},
            agt  := <! arg1>,
            obj  := <! arg2>}})
```

Though the expression "*minitsukeru*" can preserve the same vagueness as "*to wear*", it is desirable in translation to use more specific, less vague target lexical items if such lexical items (like "*kaburu*", "*haku*", etc) are available.

As Grice pointed out, there is a general principle in human communication that one should use more accurate linguistic forms than less accurate ones if they require the same linguistic efforts. If one violates this principle, hearers/readers receive extra information other than their literal meanings (implicatures). This is also the case in translation. If one translates "*to wear*" in "*to wear shoes*" into "*minitsukeru*" instead of "*haku*", the translation sounds less natural and even worse, hearers/readers may infer wrong implicatures (in this case, hearers may infer that the shoes are put on parts of the body other than feet).

As discussed in the following section, the lexical transfer in our framework is performed, first by identifying in the sortal hierarchy the vaguest possible predicates into which a source word can be converted at the logical level and then descending in the hierarchy to find expressions/words with more specific meanings. The process of descending in the hierarchy resembles the process of navigating in discrimination nets in the Schankian approach, but our framework doesn't decompose meanings of source words into semantic primitives such as M-TRANS, P-TRANS, etc. That is, our framework starts the navigation process from the middle of the hierarchy (not from the top) by using the surface source words as cues.

In the above example, the system first finds the sort [WEAR:MI-NI-TSUKERU] as the vaguest possible predicate into which "*to wear*" can be converted, and then descends the sort-hierarchy like (18) to find more specific words/expressions. In order to facilitate this process, we specify what conditions

should be satisfied for descending in the hierarchy through an S-type implication.

Actually, an S-type implication with conditions is a mixed type of S-type and C-type implications such as

(22)(→ [WEAR:HAKU](e)
[WEAR:MI-NI-TSUKERU](e)
&ARG2(e,x)&[SHOES:KUTSU](x)]).

This formula says that "[WEAR:HAKU] is a subsort of [WEAR:MI-NI-TSUKERU]" (S-type) and that "[WEAR:HAKU] has a sortal restriction [SHOES:KUTSU] on the argument-2" (C-type). Moreover, in order to descend in the hierarchy, the additional conditions ((ARG2(e,x)&[SHOES:KUTSU](x)) in the case of (22)) should be not only necessary conditions but also sufficient conditions for descending. That is, the logical relationship of the two formulae should be equivalence but not implication, such as

(23)(⟷ [WEAR:HAKU](e)
[WEAR:MI-NI-TSUKERU](e)
&ARG2(e,x)&[SHOES:KUTSU](x)).

⟷ means "equivalence".

Suppose that (23) holds, then we express the relationship of the two sorts [WEAR:HAKU] and [WEAR:MI-NI-TSUKERU] in our framework as follows.

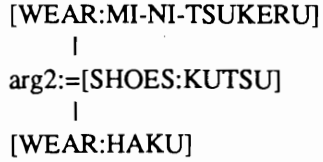
(24)
(→ [S]
SUB:[WEAR:HAKU]
SUP:[WEAR:MI-NI-TSUKERU]
CON:ARG2(self, x)&[SHOES:KUTSU](x)).

(24) expresses that

(i) [WEAR:HAKU] is a subsort of [WEAR:MI-NI-TSUKERU],

(ii) if an event - self - belongs to the sort [WEAR:MI-NI-TSUKERU] and if the argument-2 of the event belongs to the sort [SHOES:KUTSU], then the event also belongs to [WEAR:HAKU].

If we use (S) instead of [S], it shows the relationship is implication but not equivalence, which means (ii) doesn't hold. (24) is graphically represented as follows.



All the event-sorts related with "*to wear*" have the same arity (two), and we assume that the object "x" in [WEAR:HAKU](e)&ARG1(e, x) and the object "x" in [WEAR:MI-NI-TSUKERU](e)&ARG1(e, x) denote the same objects. But this continuity of argument structures through sorts is not necessarily guaranteed. A sort can have multiple supersorts and so the continuity of argument structures from different supersorts may conflict with each other.

Furthermore, it is sometimes the case that the arities of events change between a sort and its subsorts. For example, suppose that we have two event sorts [APPLY:NURU] (this event-sort corresponds to the usage of "*to apply*" in "*to apply glue/paint to ···*") *and [PAINT:PENKI-WO-NURU], and that we define the latter as a subsort of the former. Then, one of the arguments in the supersort [APPLY:NURU] is lexically included in the subsort [PAINT:PENKI-WO-NURU] so that these two sorts basically have different arities. The definition of [PAINT:PENKI-WO-NURU] is already given as (11). The definition of [APPLY:NURU] is given as follows.*

```
(25)
(Def-Pred
  [APPLY:NURU]
   {arg1 := ,
    arg2 := [PAINT:PENKI]v[GLUE:NORI],
    arg3 := ,
    eng  := {head := {e-lex := apply-to},
             agt  := <! arg1>,
             obj  := <! arg2>,
             loc  := <! arg3>},
    jpn  := {head := {j-lex := nuru},
             agt  := <! arg1>,
             obj  := <! arg2>,
             loc  := <! arg3>}})
```

The sort relationship between these two ((11) and (23)) is defined as follows.

```
(26)
(→ [S, (<*.ARG2>,<ARG2.ARG3>)]
   SUB:[PAINT:PENKI-WO-NURU]
   SUP:[APPLY:NURU]
   CON:ARG2(self, x)&[PAINT:PENKI](x))
```

<*.ARG2> and <ARG2.ARG3> in this notation mean that the argument2 in the supersort disappears in the subsort and that the argument3 in the supersort is mapped to the argument2 in the subsort. ARGi in the CON-part is taken as referring to the argument structures of the supersort, because the conditions in CON are always the conditions on the supersort for descending from it to the subsorts. Unspecified arguments remain unchanged between the sorts.

6. Inference and Paraphrasing in Translation

Inferences in the discussions so far are all concerned with sort hierarchies. Inferences based on sorts can be implemented efficiently but the forms of inferences are strictly limited. There are several cases (actually a lot of cases, if we want to develop a really high quality MT systems) which require more general kinds of inferences.

For example, though we claimed in the above section that English verb "*to wear*" can be translated into appropriate Japanese verbs by using sort restrictions on argument-2 (what is worn) and this can be done by simple forms of inference based on sorts, it is not the case. The conditions of selecting Japanese verbs are more complicated. The conditions are actually not the sorts of objects to be worn, but the place (parts of body) on which the objects are put. The verb "*kaburu*" is used when the object is put on head or face, and on the other hand, "*haku*" is used when the object is put on feet or legs. Because a "*hat*" is usually put on head and "*shoes*" on feet, the verb "*kaburu*" and "*haku*" seem to be used for the sorts [HAT:BOUSHI] and [SHOES:KUTSU], respectively.

However, in a certain situation like "*gangster in a bank*"-situation, stockings may be put on head and face to cover their faces. In this case, "*kaburu*" (which is usually used for hats) should be used instead of "*haku*" (which is usually used for "*shoes*" and "*stockings*"). That is, the constraints of the sort [WEAR:HAKU] should be expressed like

(27)
(→ C [WEAR:HAKU](e)
LOC(e, x)&([FEET:ASHI](x) v
[LEG:ASHI](x)).

Furthermore, the system has to have common sense knowledge something like {"*to wear shoes*" is usually on feet} and {"*to wear hat*" is usually on head}, etc. How to use such common sense knowledge (default knowledge) in computer systems and how to make inferences is one of the central issues in AI and it is beyond the scope of this paper. However, we can point out here that, by treating bi-lingual signs as logical predicates, we can naturally link the translation processes such as disambiguation of translationary ambiguous words, words-to-phrase correspondences, etc. with with knowledge based inference processes.

In translation of such remote language pairs as Japanese and English, we often have to change structures of source sentences completely, which seem to change not only "*structures*" but also "*meaning*" of sentences. Such structural changes cannot be treated only by bi-lingual signs, but bi-lingual signs can provide cues to trigger such global structural changes. Furthermore, we would like to treat such global structural changes not by linguistic based structure manipulations but by logical inferences.

A well known example of this type of structural changes is :

(28a)

English:	The typhoon	destroyed	many houses.
	[agt?]		[obj]

(28b)

Japanese:	Taifuu	-niyotte	ooku-no	ie	-ga	koware	-ta.
	[typhoon: n]	[cause: pp]	[many: adj]	[house: n]	[sub: pp]	[collapse: v]	[past]

As in the case of "*like*" and "*plaire*", we can think that the two structures are the same at the thematic role level by claiming that even in English the subject "*typhoon*" plays the role of [cause]-case and that in Japanese the thematic role of the syntactic subject "*ie*"(house) is [obj]-case. This line of thinking, as generative semanticists followed, leads to the lexical decomposition of "*to destroy*" by combining CAUSE (an abstract predicate) and "*to collapse*". This attitude is close to the position in MT which represent meanings of sentences by using abstract semantic primitives like Schank's CD.

However, as already pointed out by many researchers, the paraphrase of "*the typhoon destroyed many houses*" by "*the typhoon caused many houses to collapse*" looses information which the original sentence conveys (directness of the action).

Moreover, even in Japanese, the direct translation (29) is perfectly grammatical, though it is less natural than the translation of (28b) in most contexts.

(29)

Taifuu	-ga	ooku-no	ie	-wo	hakaishi
[typhoon: n]	[agt?: pp]	[many: adj]	[house: n]	[obj: pp]	[to destroy: v]

This means that we need not directly connect the English sentence (28a) directly with (28b). In our framework, the relationship between rather "literal" but less natural translations like (28b) and "natural" (as target expressions) translations like (29) by the relation of logical implication. That is, the relationship between "*to destroy*" and its lexical decomposition which leads to a "natural" translation is represented as logical implication, as follows.

(30)
(→ (S)
[DESTROY:HAKAISURU]
[(λ v)(λ w)
(CAUSE v ([COLLAPSE:KOWARERU] w))])

The supersort in this definition is a tentatively defined sort and the tentatively defined definition shows that this sort requires two arguments in its internal structures. The arguments of this tentative sort can also be referred by the predicate ARG1, ARG2, etc. The notation is a little tricky in the sense that the tentative predicate [(λ v)(λ w) (CAUSE v ([COLLAPSE:KOWARERU] w))] itself is a one-place predicate (because this is a predicate for expressing a sort), and the lambda-notation shows its internal argument structure - the variable v is the argument-1 and the variable w is the argument-2.

Note that (S) shows this relation is uni-directional and the transition from [DESTROY:HAKAISURU] to the supersort will loose some information, though the event can still be described.

The system first identifies the sort [DESTROY:HAKAISURU] to be an appropriate sort for the event which the English sentence "*the typhoon destroyed many houses*" expresses. At this stage, it can generate the translation (29). Then, the system infers by (30) that the same event can be described as another sort, that is, [(λ v) ....].

In order to materialize the idea that global structural changes in translation be explained by logical inferences, we have to clarify what sorts of inferences are appropriate, what kinds of primitive predicates like CAUSE are necessary, how to link these primitive predicates with linguistic expressions in individual languages, etc.

However, our impression is that the research in MT so far have put too much emphasis on structural issues of translation and ignore the issues concerned with "meanings". As a result, we have tried to bridge two linguistic structures simply by structural operations, even if the two structures differ from each other not only in structures but also in "contents" (or meanings). The idea of bi-lingual signs as predicates seems a good start for rectifying this excessive tendency.

7. Sketch on The Transfer Phase

Though we are now at the stage of designing a descriptive framework for bi-lingual signs, we will give brief sketches in this and following sections on how we will be able to use the descriptions of bi-lingual signs in actual systems.

As we assumed, the mono-lingual analysis phase generates mono-lingual descriptions, which are basically thematic role structures of input sentences and on which the transfer phase works. The transfer phase is virtually divided into three subphases as follows, though they can be carried out simultaneously.

(a) Transforming from thematic role structures of source sentences into schema of logical formulae (like (3))

(b) Determining logical formulae by descending/ascending sort hierarchies: during this phase, inferences based on knowledge are made, and questions are asked to users, if necessary

(c) Transforming from logical formulae to thematic role structures in the target

All of these three steps are performed by referring to the definition of bi-lingual signs. All the definition of bi-lingual signs contain the specifications which parts of linguistic expressions are transformed into the bi-lingual signs (predicates) and which parts go to their arguments, and vice versa.

We can index each bi-lingual sign by surface word whose "meanings" are expressed by the sign. "A bi-lingual sign indexed by a word" means the definition of the bi-lingual sign can be retrieved by the word. Roughly speaking, a word indexing a bi-lingual sign is either the word which appears as head in the linguistic form definitions (eng:=, jpn:=, etc) or the word which is the value in a feature marked by /. (like "nantoka" in the example [MANAGE:NANTOKA] - See (14) in Section 4).

On the other hand, for each word, we have a set of bi-lingual signs which are indexed by the word. For "*to wear*", for example, we have a set of predicates like {[WEAR:MI-NI-TSUKUERU], [WEAR:HAKU], [WEAR:KABRU], ...}. This set is the extension of the predicate schema [WEAR: ?]. Because sorts are partially ordered, we can define a set of the vaguest sorts for the word, the vaguest in the sense that none of its supersorts are not contained in the extension of the predicate schema.

The step (a) in the above is a rather straightforward process which can be recursively performed through thematic structures. At each recursion level, the system

(i) identifies the (semantic) head of the level

(ii) retrieves the vaguest possible bi-lingual signs for the head word

and

(iii) transforms the local structures governed by the head word according to the definition of the bi-lingual signs retrieved at (ii).

If the level contains words which appear under /-features like "*nantoka*" in the definition of [MANAGE: NANTOKA], the definition of the corresponding bi-signs are first retrieved to be checked whether the local structure matches the description. If matches, the system transforms the local structure accordingly, and then do the normal loop described above.

Because a predicate schemata of a word may have several vaguest sorts, step(a) produce several formulae which step(b) try to transform into more appropriate formulae. The processes of descending in sort hierarchies (disambiguation processes necessary for translation) should be performed for different predicate schema simultaneously (for verbs and nouns which are related with each other and have mutual sortal restrictions). Though the discussion so far emphasized the process of descending hierarchies, to ascend the hierarchies is also required, because the system has to instantiate all the predicate schema contained in formulae and each predicate instance has its own sortal restrictions on others. Therefore, the step(b) is a kind of relaxation process (relaxation here means to ascend the hierarchies in order to find less restrictive sorts) which try to find the most accurate solutions ("accurate" means most specific sorts). During this process, some general inference mechanisms may be invoked to infer necessary information for navigating in hierarchies and if necessary, questions will be posed to human users. We are now designing this navigation procedure for simple cases.

The final step, the step(c), is rather straightforward, because each bi-lingual signs identified by step(c) contains in the definition the information how to transform their arguments to target linguistic forms.

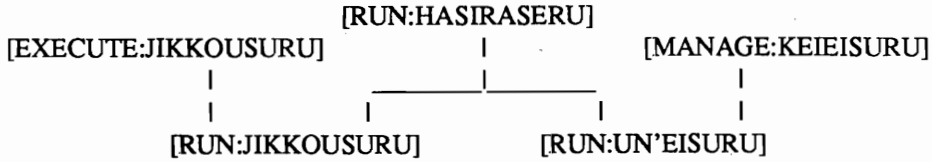
8. Disambiguation of Transfer Ambiguities by Paraphrasing

Argument structures between sorts linked in sort-hierarchies are mutually transformable, and each sort definition includes the relationships between its argument structures and the corresponding linguistic structures of both languages.

Because of this explicitness of mutual relationships among sorts and linguistic forms, we can easily express an event (or object) in diversified ways in both languages, the event which is already recognized as an event belonging to one sort. We can express it by seeing it as an event of different sorts (subsorts or supersorts of the already recognized sort) and do it in both English and Japanese. This paraphrasing facility is very useful for forming and posing appropriate questions during the transfer phase to mono-lingual speakers of the source language.

Consider the following situation:

(a) Input sentence : The teacher runs XXX.
(b) System's Knowledge about sorts :



As we have already seen, "*to run*" should be translated into several different verbs in Japanese. Suppose that the sort [RUN:HASIRASERU] is the least specific sort which "*to run*" can describe. An event of this sort can be directly transformed into Japanese expressions by using "*hashiraseru*". However, as the example of "*to wear*" and "*minitsukeru*", the direct translation is sometimes awkward if more specific lexical items are appropriate. For example, "[ORGANIZATION:SOSHIKI]-*wo hashiraseru*" can be understood but only in a very metaphorical way.

The system tries to descend in the hierarchy and find the condition for descending to the sort [RUN:UN'EISURU] that the argument-2 belongs to the sort [ORGANIZATION:SOSHIKI]. The link between [RUN:HASHIRASERU] has similar sort restrictions on the argument. One possible way of disambiguation by questions is to verbalize these sort restrictions directly such as

(c) Is XXX an organization or a name of program ?

However, what the system has to do here is to disambiguate different senses of "*to run*" which lead to different translations in Japanese, and the system knows that the two senses of "*to run*", the sorts [RUN:JIKKOUSURU] and [RUN:UN'EISURU], not only share the same supersort [RUN:HASHIRASERU] but also have their own supersorts which are not shared by the other. To verbalize these unshared supersorts can help the system to make the differences explicit. This leads to the following question.

(d) Does the teacher execute XXX ? or Does the teacher manage XXX ?

We can also think of a question which combines these two types of questions such as

(e) Does the teacher execute XXX [program] ? or Does the teacher manage XXX [organization] ?

What sorts of paraphrasing are really helpful for making ambiguities obvious to mono-lingual users requires further empirical studies. Though we use only sort hierarchies which are based on the relations of logical implication, it might be the case that the other relations among sorts like "synonym", "antonym", etc. are also useful for forming appropriate questions though their logical properties have not been well studied. Whatever relations will be necessary, our idea of bi-lingual signs which connect linguistic forms of two languages and general knowledge about events/objects denoted by them (knowledge about sort hierarchies is the simplest one of this type of knowledge) will play a key role in such paraphrasing processes.

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